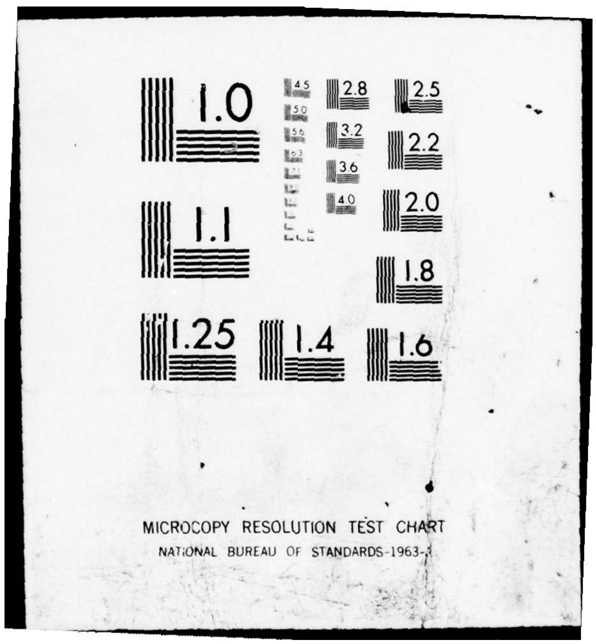
AD-A067 092 PITTSBURGH UNIV PA INTERDISCIPLINARY DEPT OF INFORMA--ETC F/G 5/10
COMPENSATION FOR VIEWING POINT IN THE PERCEPTION OF PICTURED SP--ETC(U)
MAR 79 R R ROSINSKI, J FARBER N00014-77-C-0679

UNCLASSIFIED 79-2 NL

1 OF 1
AD
A067092

END
DATE
FILMED
6--79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

COMPENSATION FOR VIEWING POINT IN THE PERCEPTION OF PICTURED SPACE

Richard R. Rosinski
Interdisciplinary Department of Information Science
University of Pittsburgh

and

James Farber
Department of Psychology
Cornell University

COMPENSATION FOR VIEWING POINT IN THE

PERCEPTION OF PICTURED SPACE

Richard R. Rosinski
Interdisciplinary Department of Information Science
University of Pittsburgh

and

James Farber
Department of Psychology
Cornell University

Research was supported by the Engineering Psychology Programs, Office of Naval Research, ONR Contract Number N00014-77-C-0679, Work Unit No. NR 197-042.

Approved for public release; distribution unlimited.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 14 79-2

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): 6 Compensation for Viewing Point in the Perception of Pictured Space.

5. TYPE OF REPORT & PERIOD COVERED: 9 Technical rep[redacted]t. Sep[redacted]77-Aug [redacted]78,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): 10 Richard R. Rosinski, James Farber

8. CONTRACT OR GRANT NUMBER(s): 15 N00014-77-C-0679

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
University of Pittsburgh 735 LIS Bldg.
Interdisciplinary Dept. of Information Science
Pittsburgh, PA 15260

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR 197-042

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE: 11 16 Mar[redacted]979

13. NUMBER OF PAGES: 56

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
ONR, Code 455
800 N. Quincy St.
Arlington, VA 22217

12 65p.

15. SECURITY CLASS. (of this report)

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distirbution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release; distribution unlimited.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Spatial perception	magnification	Surveillance
depth perception	depth perception	
vision	graphic displays	
surface orientation	texture gradients	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Graphic displays can provide a geometrically accurate representation of space if and only if they are viewed from the correct center of projection. Viewing from other locations results in distortions of the virtual space specified by the display. Despite the ubiquity of such distortions they are seldom noticed; a fact that has lead some to propose that observers can perceptually discount or compensate for these transformations of virtual space. (over)

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411 128

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The present report describes the geometric basis of representationality, and provides a specification of the distortions of virtual space in terms of the geometry of linear perspective.

The results of several studies are summarized, and it is suggested that pictorial constancy is based on both an active and a passive compensation process. The active process discounts the distortion by an amount equal to that caused by the discrepancy between the actual viewing point, and an assumed correct viewing point. The second aspect of constancy appears to be based on familiarity, and on assumptions regarding the nature of the object depicted.

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

Introduction

A fundamental problem in the study of picture perception simply involves explaining how two-dimensional pictures and photographs are capable of producing accurate impressions of three-dimensional spatial layouts. In part, this representational quality is based on similarities between the optic array projected from the picture and that from the real scene. Under "ideal" conditions a picture can present to the eye a near simulation of the scene it represents. Given a near identity of the two arrays, any theory can explain picture perception.

But this ideal case is rarely achieved or even closely approximated. As Evans (1960), Pirenne (1970), and others have noted, the pictorial array may differ from the environmental array in many respects: the presence of texture from the picture surface, a narrowing of the range of colors and luminances, the presence of borders, and so forth. Furthermore a picture is rarely viewed from the correct point of observation. Consequently, there may be striking geometrical distortions in the array that is projected to the observer's eye.

To the extent that perception of spatial relations in pictures depends on detailed geometric isomorphism, we should expect that viewing a picture from an incorrect location would affect the perception of layout. Yet ordinary experience suggests that such effects are weak or non-existent under some conditions. As we walk past a painting or photograph, we perceive, apparently accurately, what is depicted in the picture. The existence of such a constancy phenomenon has suggested to some (e.g., Pirenne, 1970) that the

perception of pictures must involve a compensation process that enables viewers to discount the effects of projective transformations on the depicted space. If such constancy processes exist, they must work only within certain circumscribed limits. A simple demonstration that such limits exist can be seen in anamorphic art. Even the simplest projective transformation used in anamorphic art can not be discounted or compensated for when the picture is viewed from the frontal-parallel. Perception of the object or scene depicted in the anamorphic painting occurs only when the painting is viewed so that the projection to the eye is similar to the projection from the real object, i.e., when geometric similarities exist between the object and its representation.

Because the precise relationships between viewing point dislocations, geometric transformations, and perceptual accuracy is unknown, determination of the correct viewing point for a display and of the effects of displacement is crucial for a further understanding of picture perception. Clearly any discussion of the way in which the visual system treats pictures, as well as any investigation of "pictorial compensation" must be based on knowledge of the transformations induced by viewing point displacement. In spite of this, there have been relatively few attempts to specify or control such transformations.

In the present chapter, we discuss the geometric effects of changing the viewing point of a picture, and consider the theoretical and empirical status of the concept of "pictorial constancy." For

the purposes of this discussion we adopt the convention of speaking in terms of photography and photographic images; of course, identical considerations hold for any geometrically representative display that has a single center of projection, such as TV or radar images, line drawings, computer graphics, etc. We distinguish between the optic arrays produced by the picture and by the environment by referring to the pictorial and environmental arrays. For a picture viewed from a given point, the spatial layout that could have generated an array equivalent to that pictorial array will be called the virtual space. Thus for each viewing point, there exists a corresponding virtual space. By definition, then, the "correct" viewing point for a picture is one in which the virtual space is identical with the geographic space that originally generated the picture, i.e., when the pictorial and environmental arrays are isomorphic.

To obtain this identity in viewing a photograph, the relationship between the eye and the photograph must preserve the relationships that exist between the lens node and the film plane. With a rigid (box) camera, the lens axis is centered on a line perpendicular to the center of the film plane, so the correct viewing point must be along a line perpendicular to the center of the photograph. The distance of the correct viewing point along this line is equal to the actual focal length of the lens multiplied by the degree of enlargement of the photograph. Thus, if the focal length of the lens when the picture was taken was 70 mm, and the negative is

enlarged 8X, then the correct viewing distance is 560 mm. Note that the correct distance is jointly a function of the focal length and the degree of enlargement. Viewing distance for a particular photograph is too close or too far away only with reference to lens and enlargement. An implication of this fact is that geometrically, transformations are not solely due to the use of particular lenses, but to the combination of lenses and viewing point. Thus, the so-called telephoto effect is not the result of using a telephoto lens, but rather of viewing a photograph from an incorrect (too near) point given a particular lens.

Similar considerations hold for determining the correct view point for a picture taken with a flexible (view) camera. All spatial relations between the lens axis and the film plane must be identical to the relations between the line of sight and the photograph. Thus, a 3 cm rise of the film plane puts the correct viewing point 3 cm (times the degree of enlargement) above the center of the photograph. The pictorial and environmental arrays are identical if the distance and orientation of the photograph relative to a line from the eye to the center of the photo are identical to the distance and orientation of the film plane relative to the line from the lens node to the center of the negative.

If these conditions are not maintained, then the pictorial and environmental arrays will differ, and the virtual space projected from the picture will differ from the environmental space.

One way to define the geometric distortions that result from changing the viewing point is to describe the virtual space that is produced. To demonstrate this point, let us consider the object in Figure 1. If this drawing is viewed from the correct point along a line perpendicular to the center of the photo, then the virtual object for the pictorial array is a cube. If the photo is viewed from another point, the virtual object for that projection will not correspond to a cube, but to some other object. If we can describe this other object, then we will have described the effects of the geometric transformation.

This section of the report will examine the geometrical basis of pictorial space perception via linear perspective representations. We will consider photographs, drawings, paintings, or other representations which can be analyzed by the principles of linear perspective, describe the rules by which the virtual space specified by such a picture can be determined, and show how the geometry of the virtual space is affected by the location of the point of observation. In particular, the way that "incorrect" points of observation produce specific transformations of the geometry of the virtual space will be explained. Although our analyses will be developed for linear perspective, the same general principles, and the same conclusions, apply to pictorial representations of spatial layout in general, as we have shown elsewhere (Farber and Rosinski, 1978).

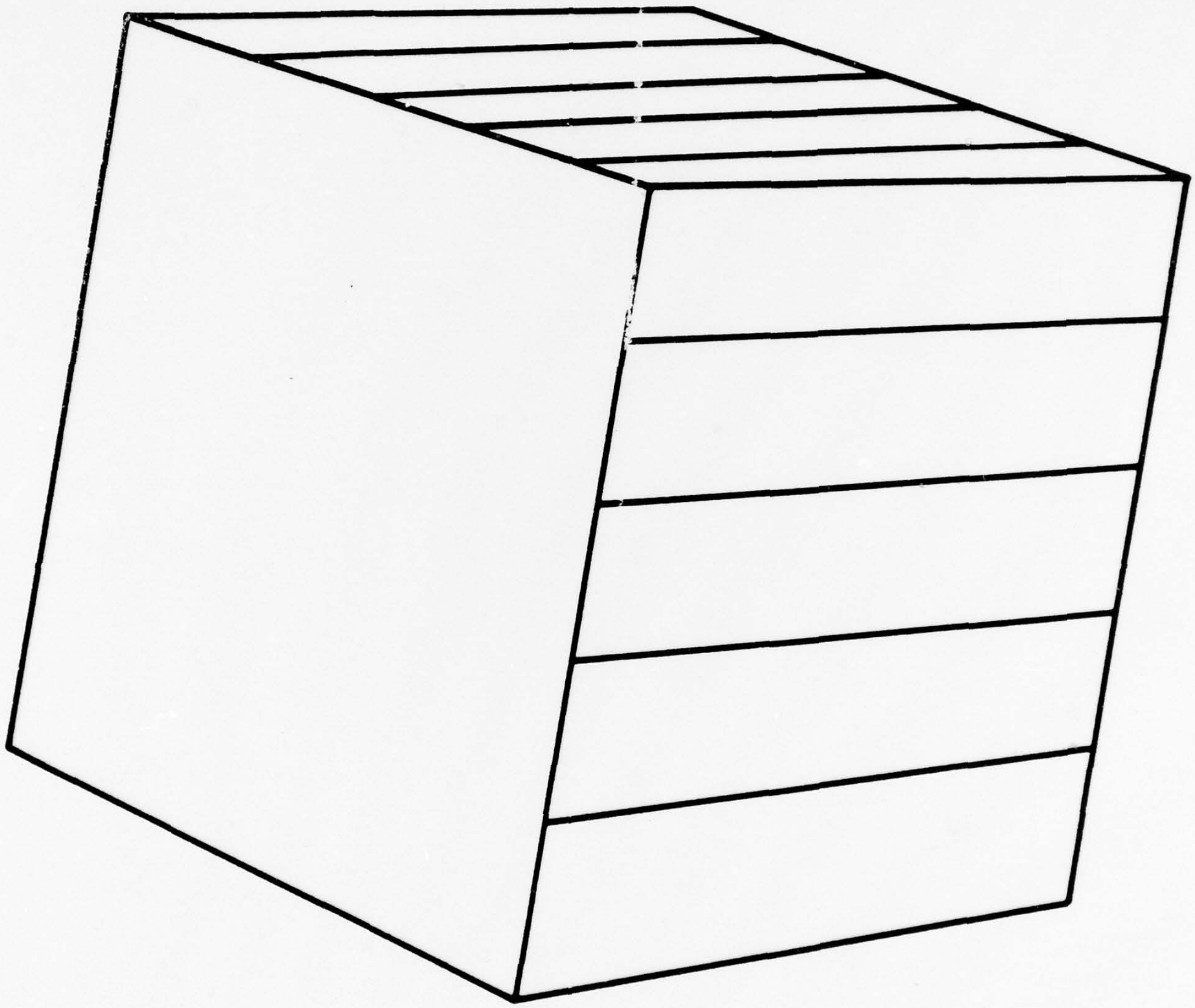


Figure 1

This drawing of a cube corresponds to a projection of an infinite number of virtual objects to an infinite number of viewing points. The object is a cube *only* when seen from one viewing point.

Decoding Spatial Layout through Linear Perspective

The rules of linear perspective can be used to represent a desired spatial layout. A picture can be constructed using these rules, so that it projects the same array to some point as a real scene. This is a case of using linear perspective for the synthesis of a spatial representation. The same principles can be used to analyze a given representation, i.e., to determine the corresponding spatial layout, given the picture and point of observation. It is possible to determine the three dimensional shape, the relative sizes, and the orientations of objects in a picture if the scene lends itself to linear perspective analysis. We will first review some rules for decoding layout from linear perspective, and then consider their implications for virtual space projected to "incorrect" points of observation.

In a linear perspective representation, parallel lines converge to a common vanishing point. There exists a point in the picture plane (corresponding to the "point at infinity" in space) which is common to all parallel lines. The direction of the vanishing point relative to the point of observation is the common direction of all lines in the sheaf. Consequently, the direction of the vanishing point specifies the direction or orientation of the set of parallel lines.

Further, lines that are coplanar converge to vanishing points that are collinear. The lines on a plane all have vanishing points that are on a line in the picture plane. Thus, there is a horizon line corresponding to each plane.

These facts are sufficient to deal with most cases of general interest. Figure 2 is the projection of a simple ground plane, consisting of a regular, rectangular texture. There is a central vanishing point at V_1, the intersection of one family of parallel sides. The orthogonal sides also project into lines that intersect in a vanishing point V_2; but the vanishing point for these lines cannot be represented in the figure, since it is at infinity in the plane of the illustration. There are two other implicit vanishing points which are of particular importance for our discussion: V_3 and V_4 are the vanishing points for the diagonals of the ground lattice. Although the diagonals are not directly represented in the illustration, they do intersect at V_3 and V_4, because for a regular ground texture, the diagonals form two sets of parallel lines.

In order to determine the geometry of the space of Figure 2, we need a scale for depth. That is, we need to know the depth shape of the ground elements; the ratio of depth to width. This requires that we specify a point of observation. We assume the viewing point for Figure 2 is at O. Note that although we have represented O in the illustration, it does not exist in the actual picture plane.

We can now determine the shape of the ground elements. This is not trivial, since trapezoidal figures, even if we assume them to correspond to rectangles, might correspond to rectangles of a wide range of shapes (d/w ratios). In fact, only for a specific center of projection does the figure represent a square ground lattice. This point is located where the angle between the observation point and the

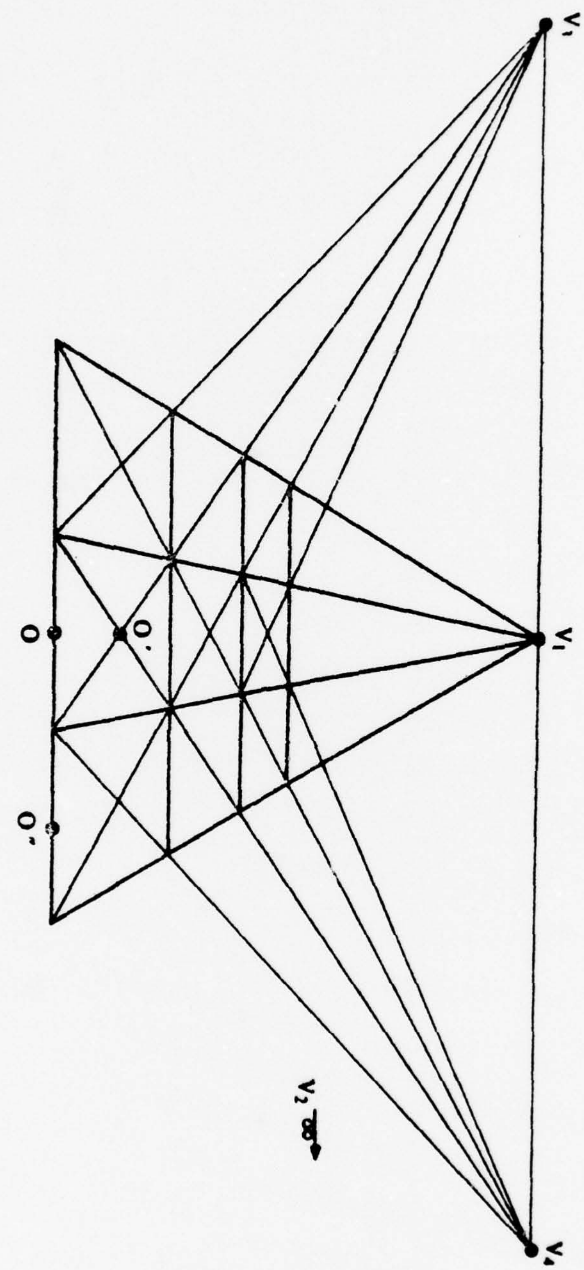


Figure 2

Schematic representation of the geometric relations important in an illustration of a ground plane of regular elements. V_1, V_2, V_3, and V_4 are vanishing points of the surface. The observation points, 0, 0', and 0" do not lie in the picture plane, but are represented in this illustration to depict angular relations.

primary vanishing points V_1 and V_2 (the angle $<V_1\ 0\ V_2$) is 90°; therefore the sides of the ground texture elements are orthogonal, and their shape is rectangular. If the angles between the diagonals and the main vanishing points ($<V_3\ 0\ V_1$ or $<V_4\ 0\ V_1$) are 45°, each element corresponds to a square, rather than any other rectangle. Of course, the absolute size of the ground elements is not specified, unless we make some assumption about the height of the original center of projection above the ground plane, but the relative sizes and distances are fully determined by the angular relations among the vanishing points and the viewing point.

In a similar fashion, the orientation of planar surfaces can be analyzed in terms of vanishing point relationships in the pictorial array. In the environment, a line from the vanishing point of a plane surface to the eye must run parallel to the surface in space. Thus, the orientation of the lines from the eye to the various vanishing points relative to the gravitational coordinate system is identical with the orientation of the surface in space. If a picture is viewed from the correct viewing point, lines from the eye to the pictorial vanishing points have the same orientation as the represented surfaces.

Effects of Viewing Point Dislocation

As the preceding analysis shows, if a picture is viewed from the correct point of observation, the angular relations between the viewing point and the various vanishing points specify the internal depth, relative size, shape, and orientation for depicted layouts. Clearly,

then, if one changes the position of the viewing point relative to the photo these angular relations are altered; and the pictured space is geometrically transformed.

Magnification

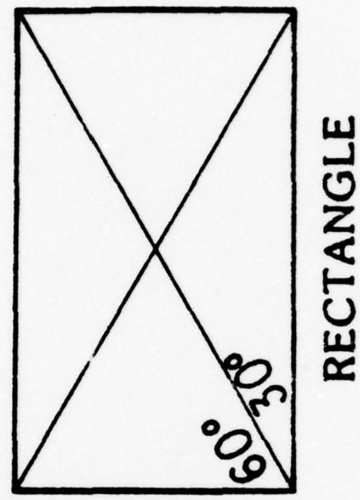
If the same picture is viewed from a different point, a different virtual space is specified. For example, if the center of projection were at O' rather than O (on the same perpendicular line, but closer to the picture plane), the diagonal vanishing point angles would be shifted. In particular, if the distance from V_1 to O = z, and if the distance V_1 O' = z', then the angle $<V_3\ O\ V_1$ is increased relative to $<V_3\ O\ V_1$, by a factor depending on the ratio z'/z. If we call these angles θ and θ', then

$$\tan \theta' = k \tan \theta,$$

where k = z/z'.

In the present case, this amounts to an increase in the diagonal angle (Figure 3), and implies a decrease in the depth/width ratio. Hence, a decrease in the distance of the center of projection corresponds to a decrease in the depth scale of the pictorial space (cf. Purdy, 1958).

So far, we have been considering the analysis of a picture, given a known center of projection. But if we analyze pictorial representations in terms of the corresponding virtual space, the same conclusions should follow for the effects of viewing a picture from a point of observation displaced along the perpendicular. Viewing a picture from a point of observation closer than the theoretical center of



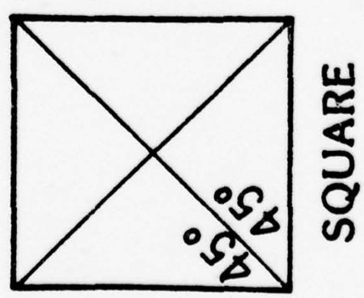


Figure 3

The angular length-width ratio and the diagonal angles of a ground element define its shape. Because magnification compresses internal depth it alters element shape.

projection produces, at the eye, an array corresponding to a space of compressed internal depth; viewing from too far produces an array corresponding to a space with an expanded internal depth scale.

Although we have been concerned with a single ground plane, the same arguments and analyses generalize to scenes containing planes in different orientations, or containing objects of different shapes, as long as linear perspective still applies. For example, consider Figure 4 (a slanted lattice against a textured ground). The ground plane is defined as in Figure 2, but there is now another vanishing line, corresponding to the horizon of the slanted checkerboard. The slant of the plane is specified by the direction if its horizon. For the case illustrated in Figure 4, and for the point of observation indicated by O, the slant is about 45°. But for a nearer center of projection (point of observation), the elevation of the horizon is increased--hence, the specified slant approaches the frontal-parallel. In addition to compressing depth in the ground plane, moving the point of observation closer to the picture also changes the specified slants of other planes.

In fact, all of the effects of changing the distance of the point of observation can be summarized by the statement that the internal depth of the corresponding virtual space is compressed by a factor $k = z/z'$. This implies the changes of slant, shape, and internal depth.

Shear

The effects we have discussed are produced by varying the distance of the center of projection or point of observation. We now consider

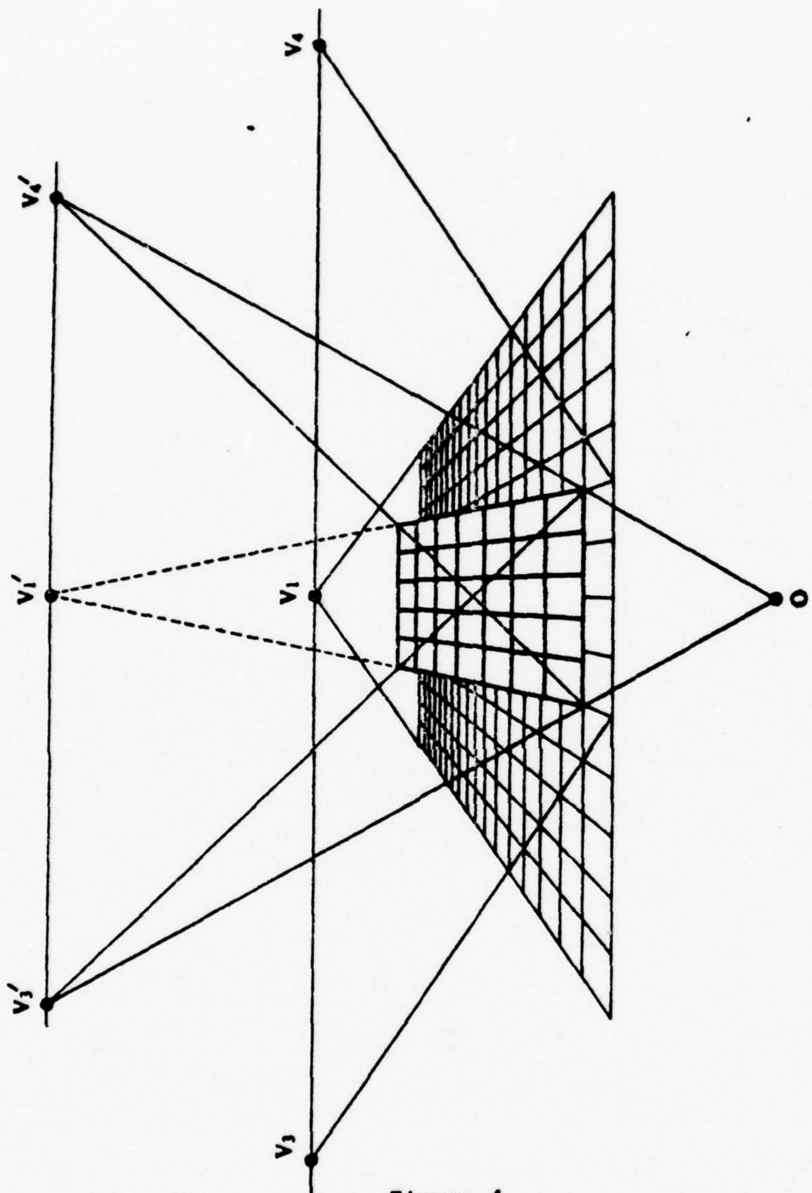


Figure 4

A lattice-like surface lying on the ground plane creates a set of vanishing points, V_1', V_2', V_3', and V_4'. These vanishing points help specify the surface's characteristics and its spatial relationship with the ground. The observation point, O, does not lie in the picture plane, but is represented in the illustration to depict angular relations.

the effects on the virtual space of lateral displacements of the point of observation (parallel to the picture plane), as illustrated by point 0" in Figure 2. Once again, we need only consider the effects on the angular relations among the vanishing points and the point of observation. Obviously, moving 0 to 0" (where 0" is to the right of 0) shifts the direction of V_1, and consequently the direction of the lines intersecting at V_1. But it also alters the angle between V_1 and V_2. The angular direction of V_2 is unaffected by the lateral shift, but V_1 is shifted leftwards; so the angle $<V_1\ 0\ V_2$ is now greater than 90°. This means that the sides of the ground elements are no longer orthogonal. The "element" of ground texture is no longer a rectangle, but a parallelogram. The effect of the lateral displacement of the point of observation is to produce a shear in the virtual space. Of course, not only ground elements, but all angular relations among non-parallel lines (as long as they are not in the same frontal plane) are sheared. In particular, although frontal-parallel lines and planes remain frontal-parallel under a lateral shift (because their vanishing points are unaffected), the orientation of non-frontal planes is angularly shifted opposite to the direction of displacement.

In the general case, both perpendicular and lateral shifts of the point of observation may occur. It is intuitively clear that the effects described here should add together: viewing from too near and too far to the right, for example, should produce both a depth compression (due to the approach along the perpendicular), and a lateral shear. We have described the quantitative relations in Farber & Rosinski (1978).

Figure 5a

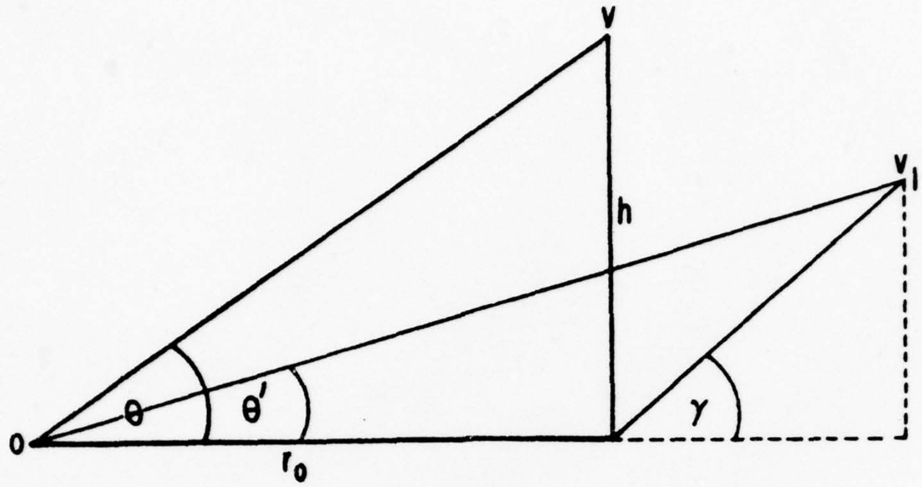
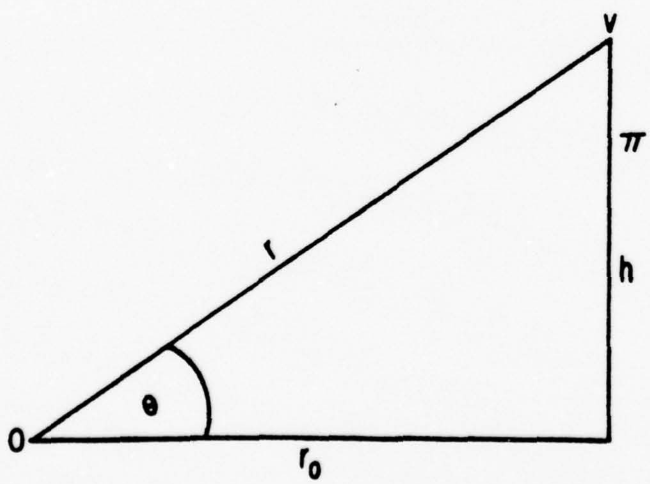


Figure 5b



A schematic side view depicting geometric relations between a point of observation, O, and the picture plane Π. V is the vanishing point for a surface depicted in the picture. A line drawn from the point of observation to the vanishing point makes the same angle θ, with the perpendicular as the surface does.

The picture plane has been rotated so that it makes an angle, δ, with the horizontal. The transformed surface slant, θ', can be expressed as

$$\cot \theta' = \left(\frac{r_0 + h \cos \delta}{h \sin \delta}\right) = \left(\frac{\cot \theta}{\sin \delta} + \cot \delta\right)$$

and as

$$\sin \theta' = \frac{h \sin \delta}{r'} = \left(\frac{r}{r'} \sin \delta\right) \sin \theta.$$

But,

$$\frac{r}{r'} = \frac{1}{\sqrt{1 + \cos \delta \sin 2\theta}},$$

and therefore,

$$\sin \theta' = \sin \theta \left[\frac{\sin \delta}{\sqrt{1 + \cos \delta \sin 2\theta}}\right]$$

Rotating the picture plane affects the relations among vanishing points of surface element diagonals. In a directly analogous fashion, such change can be analyzed as an index of shape distortion.

It is important to note once again that the effects we are discussing are "geometrical," in the sense that the transformations of virtual space are determined on the basis of considerations concerning the geometry of projection, and not on the basis of a theory about the operation of the visual system. We do not claim that the transformations of pictorial space which are geometrically specified necessarily occur in perception. That is a separate, empirical matter.

Pictorial Space Perception

The experimental literature on the effects of spatial transformations on pictorial space perception is small. There is, however, convincing evidence that, under some conditions, perceived and virtual space are in correspondence. As Gibson (1971) has argued, pictures can be representational whenever monocular arrays from a picture and from the world coincide. This, of course, corresponds to our definition for viewing a picture from the correct station point. Thus for Gibson, representationality implies that perceived and virtual space are isomorphic.

Such isomorphism exists, at least for viewing under specialized conditions. Schlosberg (1941) suggested that photographs can lead to compelling and highly realistic impressions of spatial layout under conditions which restrict the monocular field of view to the photograph. Gibson (1951) had observers view a corridor and a photomural of that same corridor. The observer's view in both conditions was through a small aperture that restricted the field of view and kept the eye at the correct point of observation. Observers were asked to decide which of the two corridors was real and which was a picture. Gibson reported that only 60 percent of the observers were correct. The results were surprising in view of the fact that the two stimulus situations differed in overall brightness, contrast, and color. Since the virtual space projected by the picture was identical to the environmental space only in terms of their geometry, difficulty in discriminating the two indicates that geometric factors played a large role in the perceptual discrimination of the two conditions.

A similar experiment by Smith and Smith (1961) illustrated this point more dramatically. In Smith and Smith's experiment, people looked through an eye piece positioned at the correct viewing points and viewed a photograph of a room containing a target on the floor. The observers were asked to toss a ball into the target under conditions that restricted their view of the picture after the ball had been tossed. There were two important aspects of the results of this study. First, the ball tossing responses of the observers were all quite accurate. In all cases, the ball would have landed on or near the target. The virtual location of the target in the pictorial space, then, determined the perceived location of the target. More strikingly, Smith and Smith report that although no attempt was made to achieve versimilitude (beyond assuring that the geometrical structure of the pictorial array matched that of the environmental array), none of the observers reported knowing that he was looking at a photograph rather than at the actual room. Thus, both in terms of qualitative impressions as well as quantitative accuracy, the structure of the geometric array is an important determiner of a pictoral space perception.

This fact, however, raises a difficult problem for an information-based theory of picture perception. If there is an isomorphism between perceived space and virtual space, pictures should be accurately representational only when they are viewed from the correct center of projection. Each projection to other viewing points specifies a unique virtual space, and each viewing point should give rise to its own unique perceived space.

It has been pointed out numerous times, that intuitively at least, such alterations in virtual space are not reflected in perception (cf. Haber, 1978, Pirenne, 1970). Impressionistically it seems that we perceive a pictorial representation of space veridically even when the geometric projection to the eye is greatly distorted. Moreover, pictures apparently look the same regardless of how we view them. We are aware of what they are intended to depict even though virtual space may be distorted.

Some individuals (e.g., Hagen, 1974; Pirenne, 1970) have speculated that picture perception involves a special perceptual process by which viewers are able to discount the distortion of virtual space caused by dislocations of viewing point. For viewing from the correct geometrical station point, perception is determined by the projected information. When a picture is viewed from the wrong viewing point, a special pictorial perceptual process is "triggered" so that different mechanisms for compensation are in effect. Hagen, like Pirenne, believes this triggering of a new process is related to picture plane cues, but she gives no indication of the mechanism involved. Hagen's position has been criticized elsewhere (Rosinski, 1976).

The various notions of compensation that have been suggested by other theorists are vague regarding the nature of these processes. The basic problem that each of them addresses is the lack of correspondence between virtual and perceived space. Because perceived space apparently corresponds more closely to environmental space than to the distorted virtual space, a mechanism is proposed to account for this

perceptual anomaly. It has been difficult to determine the nature of this mechanism, because an analysis of the distortions of virtual space has only recently been generally available.

An inability to compare perceived space with virtual space makes it impossible to specify precisely the extent and nature of perceptual compensation. Assertions regarding the existence of compensation may be in error if crucial relations among perceived, virtual, and environmental spaces are not determined. Yet, virtually every writer on pictorial distortion (the present ones included) has appealed to the reader's intuitions. For example, Haber (1978, p. 41) in discussing expected perceptions of a distorted pictorial space argues that "most picture lookers know that this does not happen." It is worth pointing out that neither such casual phenomenology nor the more experimental phenomenology of Pirenne is relevant here. The fact that observers are not consciously aware of distortions in virtual space does not imply that the nature of virtual space is unregistered by the visual system. Further, one's introspections about the nature of perceptual distortions are irrelevant. To comment on whether a picture seems distorted is to assess the correspondence between virtual and environmental space. A judgment of a distortion of space implies that virtual space is registered and somehow compared to environmental space. But, I cannot judge that this scene is distorted unless I know what it is supposed to look like. This information is not available at the incorrect viewing point. Logically, one's estimate of the distortion present in virtual space can not be accurate unless an impossible object results.

A second kind of logical problem has arisen because of difficulty in specifying the virtual and environmental spaces, and assessing their effects on perception. For example, dislocation of viewing point does not affect the relative sizes of surfaces lying in planes parallel to the picture plane. Relative sizes in any virtual space always coincide with relative sizes in the environmental space. Consequently, the perceived relative size of objects in photographs is logically irrelevant to the problem of determining the nature of perceptual compensation. The concept of compensation only need be invoked when the virtual space and environmental space differ. This makes it especially important to determine whether alterations of virtual space are reflected in the perception of space.

Effects of Magnification

One of the clearest demonstrations of the effects of magnifying the pictorial array was provided by Purdy (1960). Purdy had his observers make reproduction judgments of the slant of a textured surface under experimental conditions in which there was either no magnification or a 1.5 magnification. In addition to determining whether the conditions differed, or whether the data deviated from the predictions, Purdy used an ingenious procedure to eliminate the effects of constant errors. Since a slant of 40.9° (0.713 rad) under a 1.5 magnification geometrically specifies a surface at 52.4°(0.914 rad), Purdy had his observers judge both the 40.9° (0.713 rad) surface under 1.5 magnification as well as 52.4° (0.914 rad) surface without

magnification. Thus, a direct within-subject comparison of the perceived slant could be obtained. The two magnifications were created by maintaining a constant distance from the observer to the display, but changing the location of the center of projection. Thus available information specified the virtual orientation of the surface.

Purdy found a significant difference between judgments with and without magnification. Further, the average deviation between the judged surface slant under magnification and the geometrically predicted judgment without magnification was only 1.05° (0.018 rad). Thus, there was a remarkably close correspondence between the perceived slant of the surface and the virtual slant specified by the structure of the magnified pictorial array.

A similar correspondence has been found in other studies. Smith and Gruber (1958) used a direct scaling technique to determine the effect of viewing distance on the perception of distance in photographs. On each trial, observers viewed a corridor and a photomural of the corridor through an aperture. The experimenter designated a point in the photo, and the observer expressed the distance of that point as a fraction or multiple of the perceived distance to the corresponding point in the real corridor. The correct geometric viewing point for the photomural was at a distance of 2.1 meters. The actual viewing distances used, however, were 1.0, 1.3, 1.6, 2.0, 2.4, and 2.8 meters. Viewing from these observation points should result in compression or dilation of the virtual space depicted in the photograph. Smith and

Gruber found that the judgments did differ significantly from one another across viewing distance. In addition, by reanalyzing their data, we can see that the ratio judgments actually made in the various conditions closely matched those predicted by the distortion of the virtual space. Since $k = 2.1$ at the nearest viewing distance, and $k = .75$ at the farthest distance, the consequent compressions and dilations of virtual space differ by a factor of 2.85. In fact, actual data for these conditions differed by a factor of 2.86. Smith and Gruber point out that within any of the viewing conditions, the obtained judgment did not differ by more than 6 percent from the predicted.

The magnifications in the Smith and Gruber study were induced by varying the distance between the observer and the display. However, viewing was through a reduction aperture which reduced display plane information. Thus, in terms of both optical information and results, the Purdy study and the Smith and Gruber study are consonant.

In a further experiment, Smith (1958a) had observers view a similar photomural from two distances, and to estimate the number of paces that would be needed to go from their position to a set of pipes at the end of the hall. As one might expect from the dilation of virtual space, observers' judgments of these distances varied directly with the viewing distance of the photograph. However, the match between geometric predictions and the actual judgments was not as close in this study as in the previous ones. Given the two viewing distances used, the judgments from the far viewing point should have been about 4.5 times those from the near point. Although the judgments differed in

the predicted direction, they differed only by a factor of about 2.5 These results suggest that the geometry of virtual space affected the perception of distance, but that other factors may have been operating to reduce the effect relative to that theoretically expected.

A similar conclusion can be drawn from another study performed by Smith (1958b). In this experiment, people viewed photographs of a plowed field with 15 white stakes of varying heights positioned in the foreground and with a single white stake positioned in the background. The observers viewed these photographs at either 75 percent ($k = 1.33$) or 250 percent ($k = 0.40$) of the geometrically correct viewing distance (resulting in a magnification or minification respectively), and made judgments of the height and distance of the stake in the background. The geometrical analysis presented above indicates that under these two conditions, the virtual space of the photograph should be compressed and dilated. Qualitatively, the results followed this pattern. Judgments of distance in the two viewing conditions differed by a factor of 2.7, with the mean judgments at the 75 percent viewing distance to be in underestimation and those from the 250 percent distance to be overestimations of the actual distance of the target object. Thus, these results generally follow expectations based in the geometric deformation of the virtual pictorial space.

However, a precise reanalysis of the Smith data indicates that the match between the geometrically expected results and the data is not very close (Figure 6). For example, the average distance of the standard was 203 yards (186m). Under the viewing conditions used in the study, the geometric compression of virtual space predicts

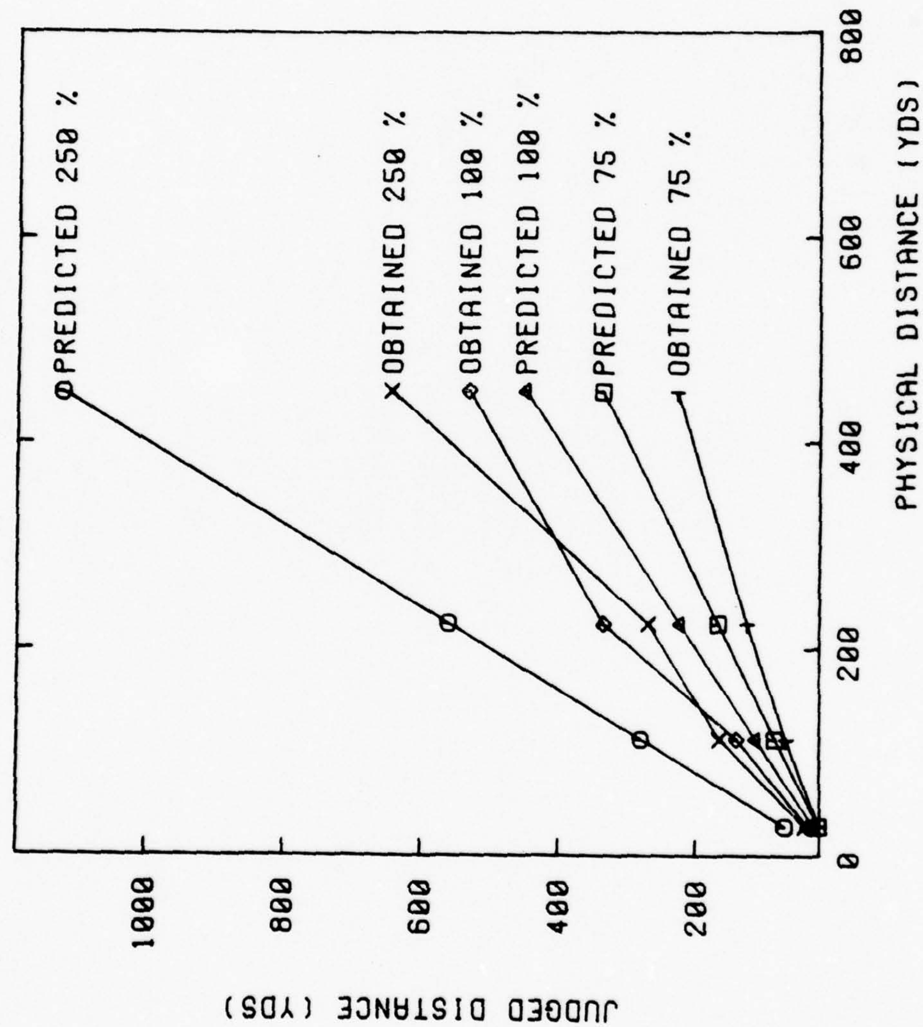


Figure 6

Mean judged distance, and predictions based on the geometry of virtual space for the physical distances used in Smith's experiment.

mean judgments of 152 yards (139m) in the 75 percent condition, since 1/1.33 (times 203) = 152 and 507 yards (464m) in the 250 percent condition, since 1/0.4 (times 203) = 507. In fact, the actual means for these two conditions were 110 (100.5m) yards and 297 yards (271.5m) respectively. Thus, it is clear that there was considerable underestimation relative to the geometrically predicted distances. Secondly, there are reasons to suppose that the effects of the 250 percent minification condition were even less than the above comparisons suggest.

Smith did not use a control condition in which observers viewed the same photographs from the correct station point. However, Gibson and Smith (unpublished) did perform such a study using the same photographs later used by Smith (1958b). Smith himself used this other set of data as a comparison for magnification or minification. For an average distance of the standard of 203 yards (136m), the mean distance judgment when viewing the photograph from the correct station point was 261 yards (289m). Thus, when viewing from the correct point, observers overestimated the distance of the standard. The virtual space projected to the correct viewing point, or with 250 percent minification differ by 304 yards (278m). Yet as shown in Figure 6 the actual difference between these two conditions was only 36 yards (33m), scarcely 12 percent of the predicted difference. The distance judgment phase of the Smith (1958b) study demonstrates that magnification of the pictorial array does exert an influence on the perception of distance, when magnification is induced by moving the viewing point relative to the picture. However, the correspondence between the

obtained and predicted judgments is so slight as to suggest that other factors are influencing the judgment. Unfortunately, the stimulus conditions are not specified in sufficient detail to determine exactly what other factors might have been operating.

The Smith (1958b) study was also constructed to determine the effects of magnification and minification on the perception of size. According to the analysis of the virtual space presented above, the relative frontal size of the object in the virtual space is not affected by viewing distance to the photograph. Subjects made size judgments by matching the object in the distance with one of 15 objects in the foreground. Smith found an extremely close correspondence between the judged and actual size of the stimulus object, which was not affected by the viewing distance. The actual size of the target object in Smith's study was 69 inches (175.26 cm) high. Subjects in the magnification and minification conditions made matching (relative size) judgments, and selected objects with mean sizes of 68.8 and 68.4 inches (174.25cm and 173.74cm) respectively. Thus, regardless of the magnification, there was no effect on the perceived size of the target object. It should be noted, however, that although the data and predictions regarding size perception match exactly, the Smith (1958b) data must be regarded as only weak support of the proposition that the virtual space affected the judgment of size. As Smith points out, the judgments of size and distance appear to be independent. Although perceived and virtual size correspond, perceived and virtual distance do not. The exact reason for this lack of a relationship cannot be directly determined, but it seems clear

that some source of relational information for size may have played a role in the judgments (cf. Sedgwick, 1973). The combination of the virtual size in the pictorial space with relational information could have resulted in near prefect judgments since relational size is not affected by magnification.

Effects of Shear

There are few experiments on the effects of the shear transformation on pictorial space perception, perhaps because of the relative complexity of these geometrically predicted transformations of virtual space. To our knowledge, there are no studies of the effects of shear on the perception of distance or orientation. The existing studies address themselves to questions of relative size and shape perception.

Perkins (1972, 1973) conducted two studies relevant to the question of the effects of the shear transformation on the perception of shape. In the first, Perkins (1972) had individuals judge whether drawn parallelopipeds were rectangular or nonrectangular. Line drawings of boxes were constructed such that half of them could not have been geometric projections of rectangular parallelopipeds. Judgments were highly accurate. In general, a line drawing of a box could be a representation of a rectangular solid only when the drawing could have been the geometric projection of a rectangular object. Perkins suggested that in the perception of shape, the visual system imposes geometric regularities (such as symmetry and rectangularity) on the object, but only to the extent that such regularities are consistent with the geometric projection. Thus, the structure of the pictorial array sets a limit upon the perception of stimulus regularities.

In a second experiment, Perkins (1973) used the identical stimulus materials, but had his observers view the pictures obliquely from angles 41° (.72 rad) or 26° (.45 rad) relative to the picture plane. As in the previous experiment, the observers' task was simply to judge whether the represented box was rectangular. The specific oblique viewing angles were chosen to determine the effect of the pictorial array on the judgment. Under these viewing conditions boxes that were orthogonally rectangular (i.e., satisfied a geometric criterion of rectangularity when viewed normally) could be either rectangular or nonrectangular in the virtual space. Similarly, some of the orthogonally nonrectangular boxes (i.e., those that would not meet the rectangularity criterion under normal viewing) could be rectangular or not in the virtual space. Thus, Perkins was able to create a conflict situation between the virtual object specified by the pictorial array and the object represented in the drawing.

There are several noteworthy aspects of the Perkins data. First, the accuracy of judgment (defined as judgments in accordance with the orthogonal classification, or in accordance with the depiction) was less for oblique viewing than for perpendicular viewing. Generally, the transformation of the virtual shape of the object did affect perceptual judgments. However, this conclusion must be qualified. When the picture was viewed at 41° (.72 rad) from the picture plane there was no effect of the virtual space on judgment. Whether the virtual object projected to the eye was rectangular or not, did not affect judgments. It is clear then, as Perkins points

out, that in this case individuals were unaffected by or able to discount the effects of the projective transformation of the virtual space induced by the dislocation of the viewing point. In the 26° (.45 rad) viewing condition, however, the conflict between the orthogonal and the virtual object resulted in substantially inferior performance. In this condition, there was clear evidence that the perception of shape was affected by the structure of the virtual space. Thus, the perception of shape is partly determined by nonoptical factors and is not in simple correspondence with the virtual space, but the geometric transformation does exert some influence on judgment.

Perceptual Compensation for Geometric Distortion

It is unfortunate that there is some inconsistency among studies performed in the past. Under some conditions, space perception of transformed pictures seems to be directly influenced by the geometry of the virtual space represented by the pictorial array. Other research indicates that factors in addition to the simple geometry of the virtual space affect perception. Of course, the differences among studies must be directly related to display content and viewing conditions. Unfortunately, many of the early experiments are not sufficiently descriptive to allow us to unequivocally explain discrepancies among studies. Some provide virtually no information regarding viewing conditions, and others provide insufficient descriptions to allow us to determine exactly what information was available to the observer.

There are, however, common threads throughout the literature which suggest that there are certain constraints on the operation of a compensation process. First, it appears that perception of familiar objects or objects within a familiar spatial context is relatively unaffected by distortion of virtual space. Familiarity apparently overrides distortions in the array. Secondly, perception seems to be in greater correspondence with the virtual space when picture plane cues are eliminated or minimized, or when the optic distortion is not induced by charges in viewing point (as in Purdy's experiment discussed above).

We can see why familiarity and/or availability of display plane information moderates the effect of distortion by analyzing the nature of pictorial perception. Operations and states involved are represented in Figure 7. In the simplest case, there exists an environment represented in the display. If the display is viewed from the correct point the transformation is an isomorphic one, and virtual space and environmental space are identical. Perceived space corresponds to environmental space within the limits of the pick-up process, and there is no need for any compensation. This is, of course, the simplest, most straight-forward circumstance, and one that corresponds to one aspect of the Gibsonian position.

The intriguing problem occurs when we introduce a transformation. How is it possible for perceived space to correspond to the environmental rather than virtual space? One trivial possibility

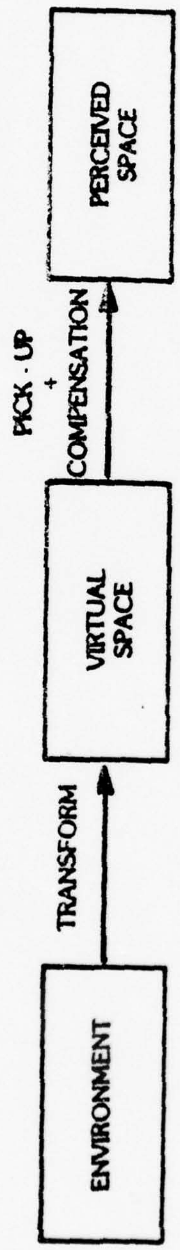


Figure 7

A minimal set of operations and states involved in perceptual compensation for distortion in virtual space.

is that familiarity overrides any distortion of virtual space. We know somehow that this is a picture of our friend and see her despite the distortion. This is scarcely perception, of course, but more like social cognition (cf. the Honi phenomenon).

As a second method of accounting for "compensation phenomena," we hypothesize a passive perceptual mechanism that renders the visual system relatively insensitive to distortions of virtual space. There are at least two related ways that this could be passively accomplished, either through perceptual persistence or categorization. We have in mind a situation analogous to that reported by Julesz (1971) for binocular vision. In stereopsis, if two stereogram halves are fused, disparity may be increased well beyond Panum's area before diplopia results. In similar fashion, once an object, scene, or spatial relation is identified or categorized, distortions of virtual space must be extreme before they affect judgments.

Although he is not explicit on this point, this would appear to be a type of mechanism consistent with the findings of Perkins (1973). Perkins suggested that there is a minimal geometric criterion for rectangularity. Consider a two-dimensional line drawing in which three lines meet at a point. For this configuration to be a geometrically possible projection of a rectangular corner, the three angles must all be greater than 90 degrees; or in a special case, two of the angles must be exactly 90 degrees.

If an object satisfied this minimal criterion, it would be seen as rectangular. Individuals viewed pictures of boxes from viewing angles of 41 degrees (.72 rad) or 26 degrees (.45 rad) from the picture plane. When the picture was viewed from the 26 degree (.45 rad) location, judgments were strongly affected by the virtual space. Such results suggest that for certain familiar objects such as parallelopipeds, categorical perception may occur. As Pirenne (1970) has suggested, shifting perceived shape away from the familiar category may take a substantial distortion of virtual space.

It seems also that such a view would be consistent with a recent portion of Gibson's theorizing. He holds that under certain conditions (correct viewing?) the pictorial array can act as a surrogate source of information. Under other circumstances (those in which projective equivalence is lacking) pictures may simply function as mediators or symbols for objects or spatial environments. We also acknowledge that one aspect of perception of pictorial distortion may simply be a case of pattern matching or categorical judgment.

However, a more interesting aspect of compensation is, How might an unfamiliar scene be treated? It could be recognized as a scene via pattern matching, but details of layout are not given in the categorization of unfamiliar landscapes. The observer has available only the virtual scene projected to the eye. Accurate perceptual judgments that correspond to the environmental space

require knowledge of the transformation operating on the scene. However, such knowledge is not available in the optic array. There is an infinity of distortions or transformations and none of them can be determined for an unfamiliar scene solely on the basis of the virtual space.

If judgments do not conform to the virtual space, but show a correspondence to the environmental space, the transformation must be estimated by the visual system even though there may be no mathematically sufficient basis for the estimate. The importance of display plane information suggests that the ability to determine viewing point relative to the display affects this estimate.

We propose as an explanation of pictorial compensation an active perceptual process that undoes or discounts the effects of distortions of virtual space. There are several necessary characteristics of such a process. Ideally, such an active compensation mechanism would operate when virtual space distortions were present, but not when virtual and environmental space were isomorphic. Yet, as we have pointed out, there is no way that one can tell that virtual space is distorted without having knowledge of the correct environmental space. The operation of an active compensation process must depend, then, on certain assumptions and inferences about viewing pictures.

Such an active process would operate when the actual viewing point (given by stereopsis, parallax, accommodation, etc.) did not correspond to the assumed correct viewing point. Assumptions regarding the correct viewing location could be based on a variety

of experiential or optical considerations. For example, paintings, drawings, and photographs are often prepared for viewing from a point along a perpendicular to the center of the display. Thus, for many displays the center of projection may correctly be assumed to be along a line normal to the display plane.

Distance along this line may be given by experience or optical clarity. For example, standard print formats have evolved so as to insure that they subtend approximately the same angle at the standard viewing distances. Approximately the same distance relations are given in considering fidelity of televised pictures. For standard TV displays, signal to noise ratios are highest at viewing distances of approximately twice the height of the display. Thus for both photographic and electronic displays, presentation conditions may lead to an assumed correct viewing point along a line perpendicular to the center of the display and at a distance of twice the display height.

Such a set of assumptions provides a specification of the correct viewing point in terms of the relations to the picture plane. It is important to point out certain important consequences of the assumptive approach. First, it is obvious that such assumptions are learned on the basis of exposure to specific displays. Children or others with restricted experience may not have developed such abilities. In much the same fashion, technological and cultural differences may affect specific learning. For example, use

of a different video standard, e.g., the European standard, gives slightly different signal to noise ratios as a function of distance. Thus assumptions regarding video displays may be somewhat altered. Animals or individuals deprived of pictorial experience may have no learned assumptions about pictorial viewing; their picture perception may be based totally on the virtual space or on pattern matching. For them, space perception in pictures may simply be a case of pattern matching of virtual space.

Further, it is necessary to acknowledge that the various compensation mechanisms proposed here are interrelated. For example, both familiarity with, and assumptions about the environmental space could contribute to the estimation of correct viewing point. If certain assumptions are made about what is depicted, the range of potentially correct viewing points is greatly reduced. Consider a display containing two surfaces meeting in a dihedral angle. The lines from the viewer's eye to the two implied vanishing points must meet at the same angle as the two planes. Thus, if it were assumed that the corner were rectangular, the possible correct distance of the viewing point would be constrained to one value. Similarly, if it is assumed that a plane is perpendicular to the frontal, then the correct viewing point must lie along a line perpendicular to the implied horizon. In this way, perceptual assumptions about the nature of surfaces and orientations could indicate positions for the correct viewing point. Deviations from such an assumed correct point could be the basis for compensation.

If compensation is based on an assumed correct viewing point relative to the picture plane, the availability of picture plane information should affect the degree of compensation. Recently, we have completed several experiments in our laboratories which bear on these various mechanisms for pictorial compensation. In the first, observers were required to make modulus-free magnitude estimates of the sizes of objects depicted in photographs. The objects were gray, square parallelopipeds 6 cm in height and varying in width. The photos were prepared using a 4 x 5 view camera so that three facets of the object were visible, and so that the center of projection was 25 cm. away from the center of the photograph.

The photographs were viewed at distances of 25 cm., 50 cm., or 75 cm. by observers whose heads were held motionless in a chin rest. All viewing was binocular, with the matted photograph held in a rectangular frame. The observer's head was held in position by a chin rest, and both the chin rest and photos were held in position on an optic bench.

The three viewing conditions employed in this study correspond to magnifications of 1.0, 0.5 and 0.33. Effects of such viewing conditions on virtual spaces are easily determined. By the rationale presented earlier, minification results in an expansion of virtual space. Thus, the width of the object is affected. The precise amounts of geometric expansion under these three conditions are presented in Table 1.

Table 1

Actual Size and Virtual Size of

Object under 2 Minifications

Actual Size	Virtual Size	Virtual Size
m = 1.0	m = 0.5	m = 0.33
1.0	1.56	2.21
1.5	2.34	3.31
2.0	3.14	4.41
2.5	3.90	5.52
3.0	4.68	6.62
3.5	5.46	7.73
4.0	6.24	8.83
4.5	7.02	9.94
5.0	7.80	11.04
5.5	8.59	12.14
6.0	9.37	13.25
6.5	10.15	14.35
7.0	10.93	15.46
7.5	11.71	16.56
8.0	12.49	17.67
8.5	13.27	18.77
9.0	14.06	19.89
9.5	14.86	21.00
10.0	15.61	22.10

Although the estimates of the subjects were scale-free, we can easily determine the relationship between environmental, virtual, and perceived space. It is well known that the relationship between magnitude estimate of size and physical extent is linear, i.e., a power function with an exponent of 1.0, (Marks, 1974). If perceptual compensation for viewing point occurred, all functions should be linear with a slope of 1.0. If the perceived space matches the virtual space, we should expect slopes equivalent to the relations in Table 1. That is, with m = 1.0, the slope should be 1.0; with m = 0.5, the slope whould be 1.40 and with m = 0.33, slope should be 1.99.

The results of this experiment are presented in Figure 8. It is immediately clear from the figure that almost complete compensation occurred. There was essentially no effect of the virtual space relationship on judgment. Virtually identical results were obtained using line drawings that were projectively equivalent to the edges of the objects in the photograph. Figure 9 depicts those data. Although different people were used, and consequently a different modulus is evident, almost identical relationships are obtained. Thus it is clear that virtually complete compensation takes place for expansion of virtual space due to minification.

One difficulty with these results is that although we are assured that compensation occurred, we have no means of determining its basis. Given the experimental conditions, any or all of the

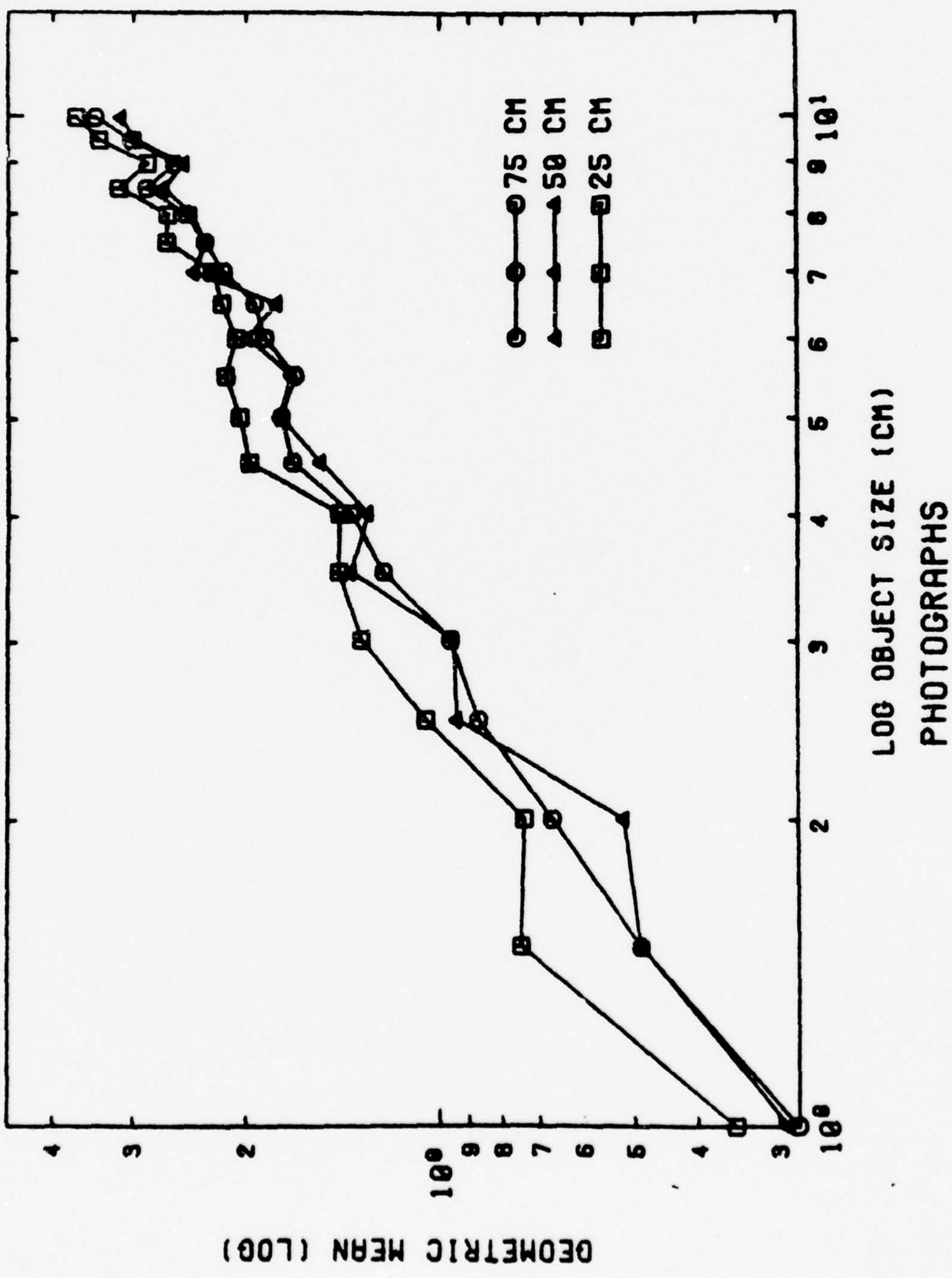


Figure 8

Mean magnitude estimates (log scale) as a function of object size. Viewing distance is a parameter. Data collected for photographs.

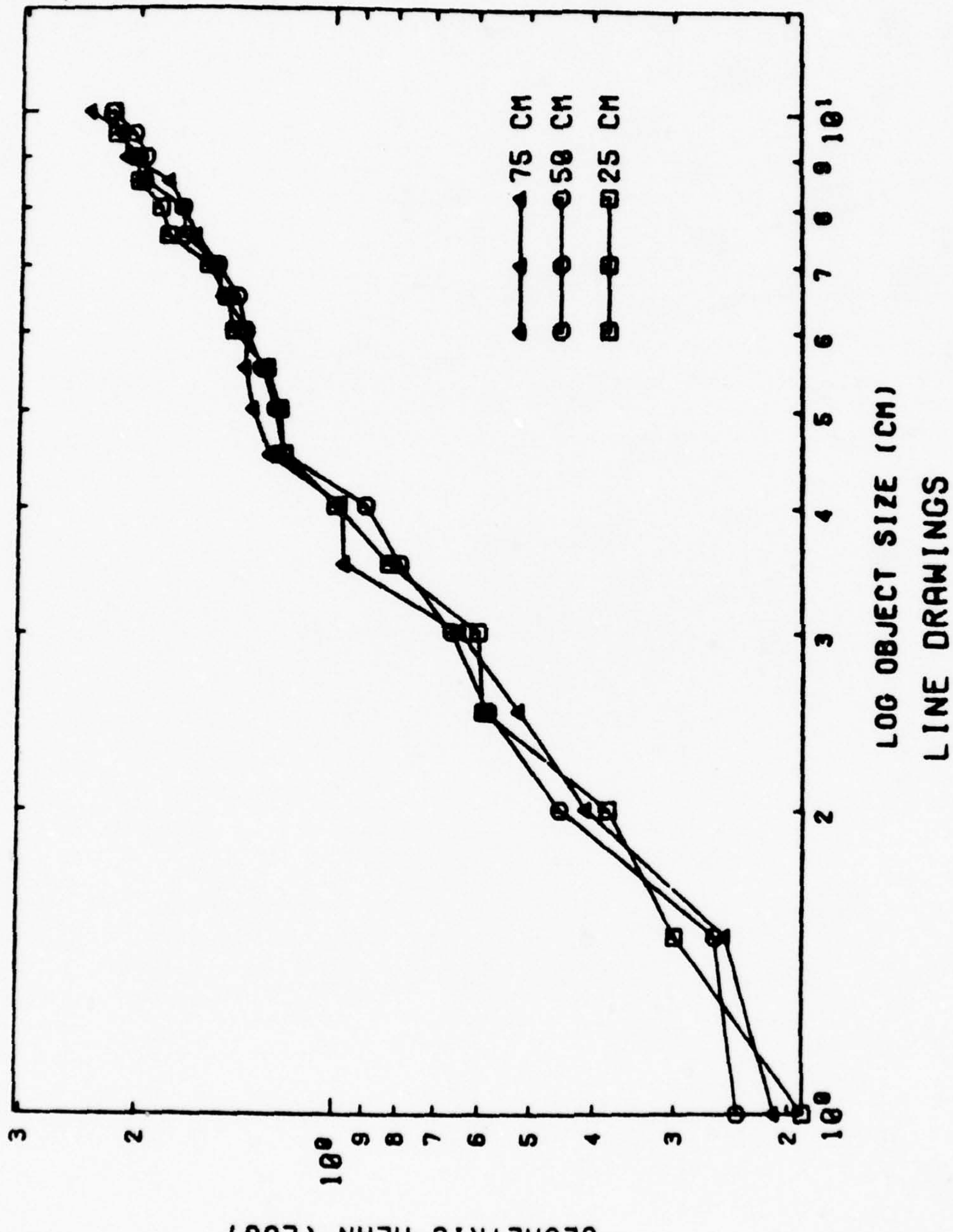


Figure 9

Mean magnitude estimates (log scale) as a function of object size. Viewing is a parameter. Data for line drawings.

mechanisms discussed above could have been operating. For example, the objects may have been categorized as rectangular regardless of the virtual space, and observers' estimates based on shape relations. Or an assumption about the correct viewing point could have been made based on picture plane location or on vanishing point relations. In order to avoid such difficulties, and to determine more precisely the extent and nature of pictorial compensation we have undertaken several other experiments examining other indicators of perceptual accuracy.

One consequence of the dilation/compensation of space which results from changes in viewing point involves changes in virtual orientation. Magnification makes the virtual orientation of surfaces more frontal, minification makes it less frontal. Thus to evaluate the nature of compensation for distortion, we have used observer's direct scale estimates of orientation of lattices. In our studies of magnifications, slanted lattices were computer-generated and displayed on a CRT. Observers viewed the display binocularly and made direct estimates of orientation in degrees and expressed their response on a computer keyboard. The convention was adopted with 90 degree being the frontal, and orientations with the top edge further away were denoted as less than 90. In the first experiment, observers always viewed the display from 112 cm.; however, the correct center of proportion across conditions was 28, 56, 84, 112, 225, 337, and 450 cm. Thus 7 degrees of magnification (m = 4.0 to m = 0.25) were induced. The virtual orientation

of surfaces under these magnification/minification ratios is depicted in Figures 10 and 11. No independent information for the slant of the lattice was available, and the distance between viewer and display was constant. Consequently, the exact nature of the transformation and its degree is not specified optically. Under such conditions, we should expect that judgments should be determined by and in correspondence with virtual space, at least within limits imposed by familiar size and shape.

The data for this experiment are depicted in Figure 12 for magnifications, and in Figure 13 for minifications. It is evident from comparing these figures that the range of judgment is restricted. As has been verified in numerous experiments, slant judgments in a variety of experimental circumstances tend to be more frontal than is specified by the virtual space. The reduced range of judgment in the present case is probably the result of the conflict between monocular perception and binocular information for the display plane. However, there is no doubt that, within the general accuracy constraints for slant perception, virtual space exerts a significant influence on perception. For the most extreme minification of .25, the relation between judgments and physical slant is primarily linear with a slope of approximately .8. For the most extreme magnification, the relationship is cubic. It is worth pointing out

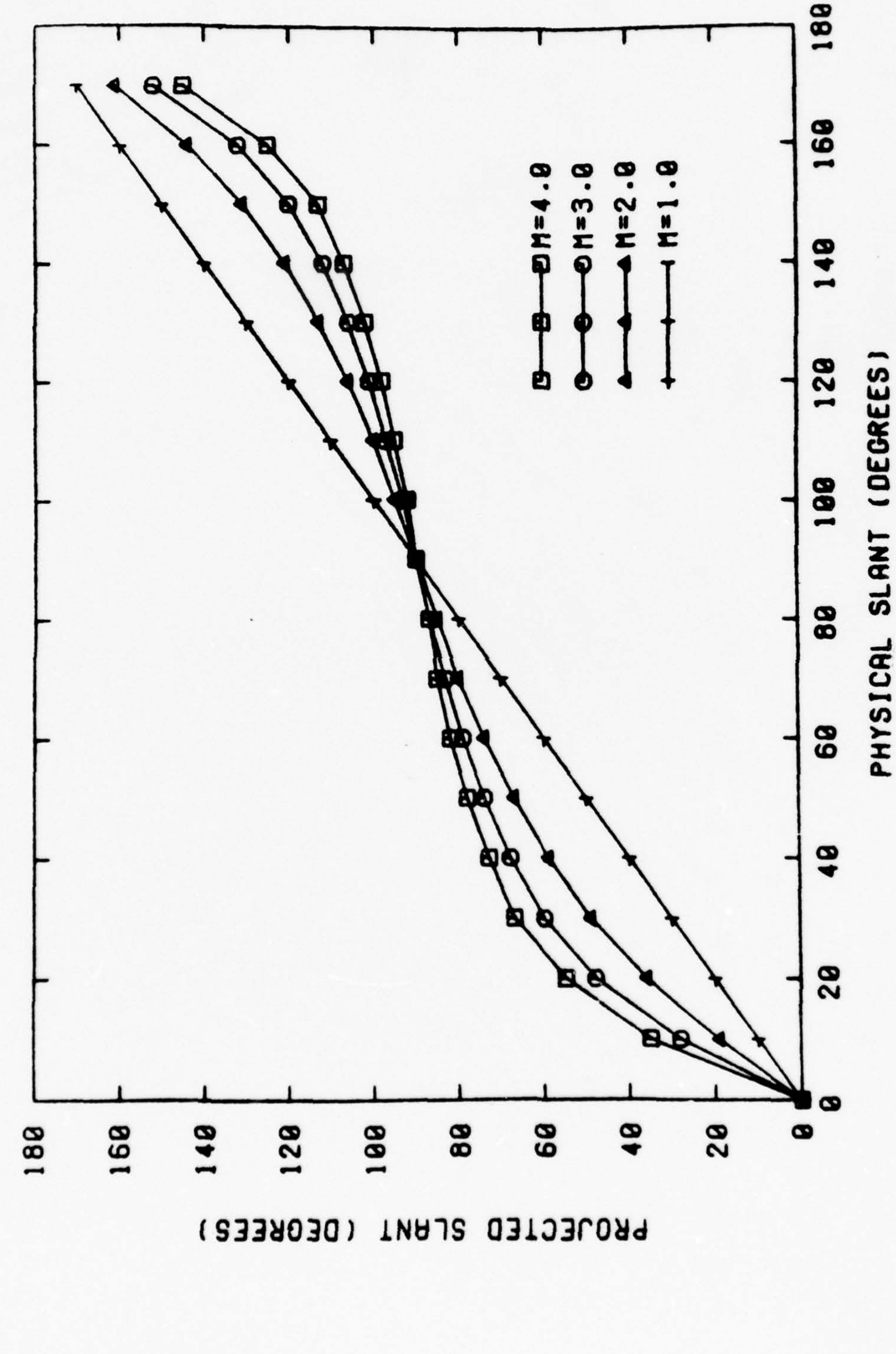


Figure 10

Virtual surface orientation as a function of physical orientation and degree of magnification.

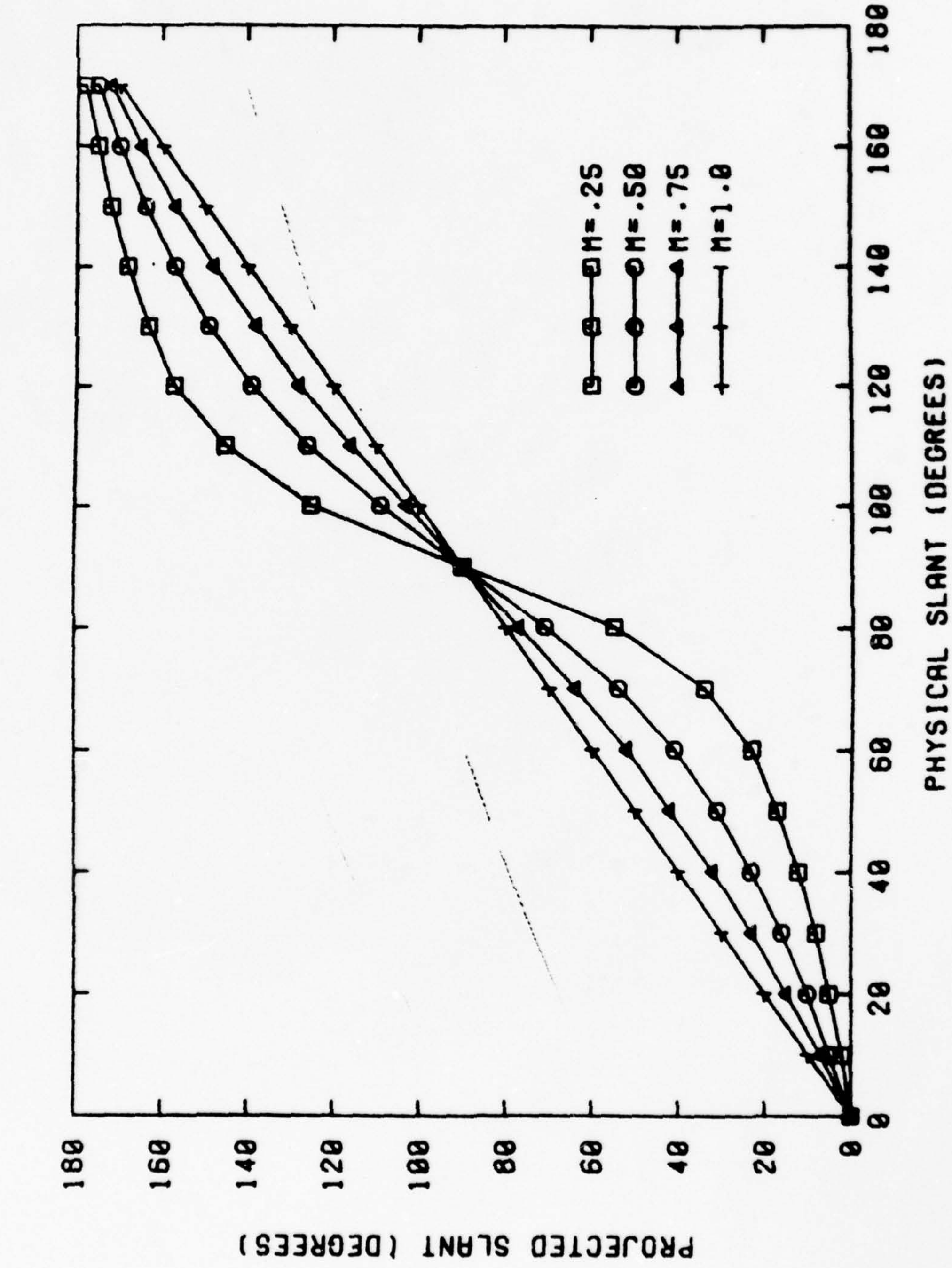


Figure 11

Virtual surface orientation as a function of physical orientation and degree of minification.

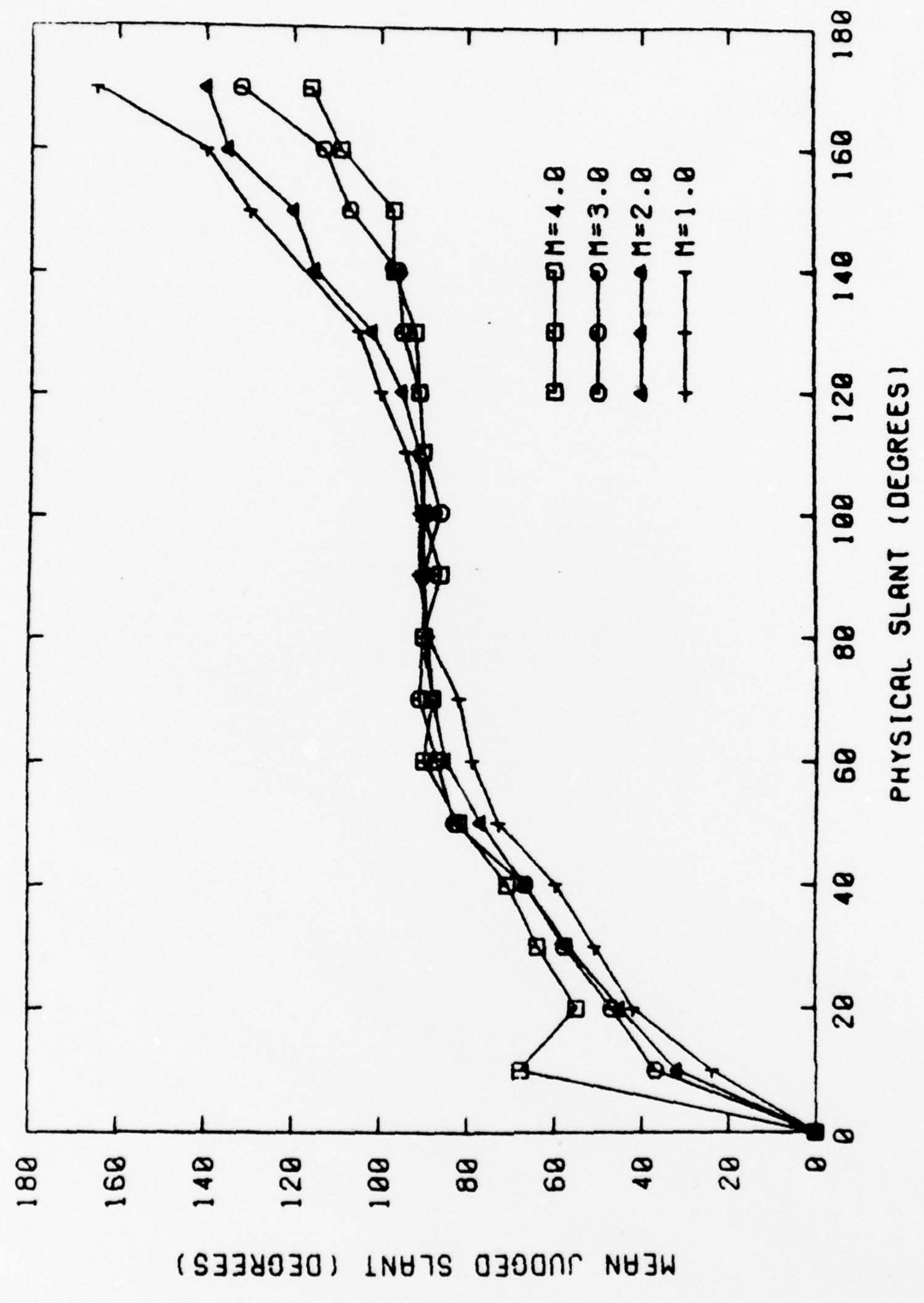


Figure 12

Perceived orientation of physical slants under minification.

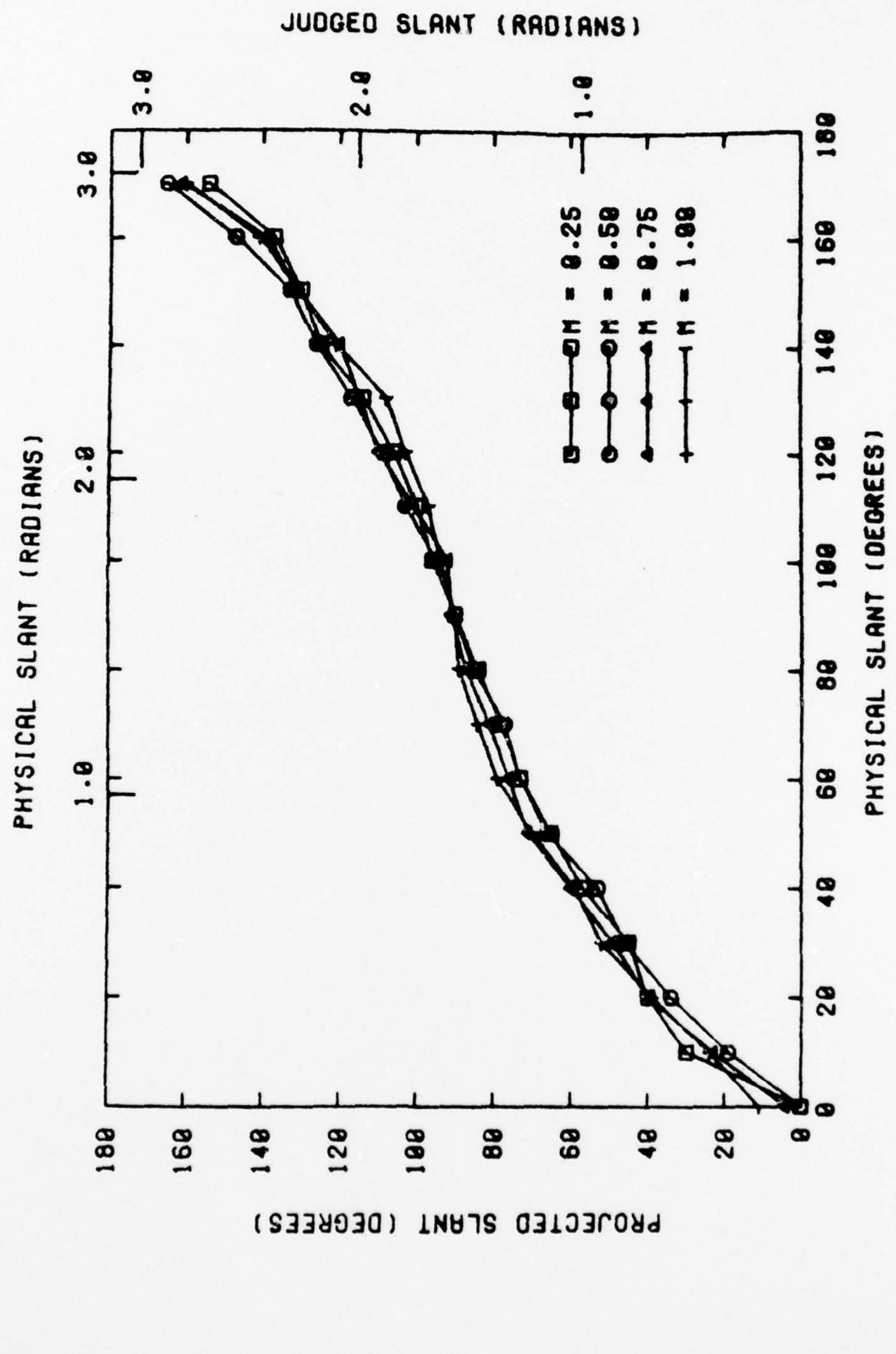


Figure 13

Perceived orientation of physical slants under minification.

These results suggest that the compensation for display plane orientation occurs when the viewing angle from the eye to the display varies from some system reference value. Such a set of picture viewing assumptions would account for the operation of a compensation process. We propose that the process itself is a relatively simple one that discounts the effects of viewing point dislocations. Consider a situation, like that described above, in which an individual makes judgments of the orientation of a surface while viewing a display that is slanted relative to the line of sight. Since θ' is specified by surface gradients, and δ by binocular vision or frame perspective, exact correspondences for θ could be determined using the relationship defined in the equation above.

Although such a process may appear rather complex, a function of the sort described above is necessary. In our experiment, virtual orientation was a curvilinear function of environmental orientation when the display plane is viewed at a slant. Yet for both the 45° (.79 rad) and 135° (2.36 rad) viewing angles, judgments of orientation were collinear without higher order components. This indicates that the compensation process is a non-linear one, and also indicates that simple differences between θ and δ can not be the basis of compensation.

The present hypothesis can also account for the paradox of picture-in-a-picture perception (Pirenne, 1970). Consider a slanted surface viewed directly, with a horizontal line of regard, then surface slant, θ, equals projected slant, θ'. If a photograph of

the surface is viewed from the wrong station point, projected slant, θ', is a function of surface slant, θ, and angle δ as given by the above equation. If this photograph is itself photographed and the second photo is viewed from the wrong station point, a second transformation occurs, and projected slant, θ'', is a function of θ', θ, δ, and δ'. The paradox results from the fact that it is apparently difficult to compensate for the transformation while viewing the second photo. If the second photograph is viewed from its correct station point, a situation geometrically equivalent to that in the above experiment is obtained, and compensation could only occur if δ (the inclination of the first photograph relative to the optical axis of the camera taking the second picture) is known (see Pirenne's Figures 8.1 and 8.2 in this regard). If the second photograph is viewed from the wrong station point, two transformations occur and compensation (accurate perception of θ) requires accurate estimates of θ'', θ', and δ', and δ. Consequently, errors in estimating any of these parameters will result in errors of compensation. Additionally, since two transformations involving nested calculations are involved, such errors will be exaggerated. Further, since binocular or monocular cues do not specify the orientation of the first picture relative to the second or relative to the observer, an estimate of δ may be unavailable to the observer.

A similar process can be proposed based on the assumed content of the display rather than the assumed viewing relations. For a familiar object, the discrepancy between θ' (registered) and θ (assumed) is an indicator of δ. This value of δ can then be used in applying compensation processes to other objects and surfaces depicted in the display. There is evidence that such assumptions

regarding context can affect compensation. Cooper (unpublished) required adults to judge rectangularity of parallelopipeds which were distorted in virtual space by a shear. When the object was included in the display so that its edges and sides were parallel to the corners and walls of the room (also in the display), judgments were essentially perfect. When the position of the target was altered so that edges and sides were not parallel to the room's corners and walls, judgmental accuracy decreased to 70%. The relationship between the distorted objects and the reference axes provided by the assumed rectangularity of the room provided a way to discount distortions of virtual space.

In summary, the lack of a strict correspondence between perceived and virtual space, coupled with the existence of correspondences between environmental and perceived space suggest that pictorial perception involves a unique visual compensation process. We propose two possible mechanisms that may be involved in such compensation. First, a simple, passive pattern matching may be involved. Once an object or pattern meets certain minimal criteria, categorization occurs. Extreme distortions are necessary before such categorization can be overcome.

Secondly, we propose the existence of an active perceptual compensation process that discounts optical distortions caused by changes in the viewing point. Since there is no optical information for the correctness of viewing point, such compensation must be based on assumption regarding appropriate viewing conditions for

representational displays. The research that we have conducted indicates that observers can compensate for both the effects of shear and of magnification on spatial layout. Our data suggest that compensation is a non-linear process modulated by the difference between actual and assumed correct viewing points. The actual location of these assumed correct points, and the means by which such assumptions develop are clearly two important issues for future work in pictorial space perception.

REFERENCES

Evans, R. M. Eye, film, and camera in color photography. New York: Wiley, 1960.

Farber, J., & Rosinski, R. R. Geometric transformations of pictured space. Perception, 1978, 7, 269-282.

Gibson, J. J. A theory of pictorial perception. Audio-Visual Communications Review 1, 1951, 1-23.

Gibson, J. J. The information available in pictures. Leonardo, 1971, 4, 27-35.

Haber, R. N. Visual perception. In M. R. Rosinzweig & L. W. Porter (Eds.) Annual Review of Psychology, 1978, 29, 31-59.

Hagen, M. A. Picture perception: Toward a theoretical model. Psychological Bulletin, 1974, 81, 471-497.

Julesz, B. Foundations of cyclopean perception. Chicago: University of Chicago Press, 1971.

Marks, L. E. Sensory processes. New York: Academic press, 1974.

Perkins, D. N. Visual discrimination between rectangular and non-rectangular parallelopipeds. Perception & Psychophysics, 1972, 12, 396-400.

Perkins, D. N. Compensating for distortion in viewing pictures obliquely. Perception & Psychophysics, 1973, 14, 13-18.

Pirenne, M. H. Optics, painting, & photography. Cambridge: Cambridge University ress, 1970.

Purdy, W. C. The hypothesis of psychophysical correspondence in space perception. Ithaca, NY: General Electric Advanced Electronics Center, September 1960. No. R60ELC56.

Rosinski, R. R. Picture perception and monocular vision: A reply to Hagen. Psychological Bulletin, 1974, 83, 1172-1175.

Schlosberg, H. Stereoscopic depth from single pictures. American Journal of Psychology, 1941, 54, 601-605.

Sedgwick, H. A. The visible horizon: potential source of visual information for the perception of size and distance. (Doctoral dissertation, Cornell University, 1973). (University Microfilms No. 73-22,530)

Smith, O. W. Comparison of apparent depth in a photograph viewed from two distances. Perceptual and Motor Skills, 1958a, 8, 79-81.

Smith, O. W. Judgments of size and distance in photographs. The American Journal of psychology, 1958b, 71, 529-538.

Smith, O. W., & Gruber, H. Perception of depth in photographs. Perceptual and Motor Skills, 1958, 8, 307-313.

Smith, P. C., & Smith, O. W. Ball throwing responses to photographically portrayed targets. Journal of Experimental Psychology, 1961, 62, 223-233.

OFFICE OF NAVAL RESEARCH

Code 455

OSD

CDR Paul R. Chatelier
Military Assistant for Training and Personnel Technology
Office of the Deputy Under Secretary of Defense
OUSDRE (E&LS)
Pentagon, Room 3D129
Washington, D.C. 20301

Foreign Addressees

North East London Polytechnic
The Charles Myers Library
Livingstone Road
Stratford
London E15 2LJ
UNITED KINGDOM

Professor Dr. Carl Graf Hoyos
Institute for Psychology
Technical University
8000 Munich
Arcisstr 21
FEDERAL REPUBLIC OF GERMANY

Director, Human Factors Wing
Defence & Civil Institute of Environmental Medicine
Post Office Box 2000
Downsville, Toronto, Ontario
CANADA

Dr. A. D. Baddeley
Director, Applied Psychology Unit
Medical Research Council
15 Chaucer Road
Cambridge, CB2 2EF
UNITED KINGDOM

Department of the Army

Mr. J. Barber
HQS, Department of the Army
DAPE-PBR
Washington, D.C. 20546

Dr. Joseph Zeidner
Technical Director
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Director, Organizations and Systems Research Laboratory
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Edgar M. Johnson
Organizations and Systems Research Laboratory
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Technical Director
U.S. Army Human Engineering Labs
Aberdeen Proving Ground, MD 21005

U.S. Army Aeromedical Research Lab
ATTN: CPT Gerald P. Krueger
Ft. Rucker, Alabama 36362

ARI Field Unit-USAREUR
ATTN: Library
C/O ODCSPER
HQ USAREUR & 7th Army
APO New York 09403

Department of the Navy

Director
Engineering Psychology Programs
Code 455
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217 (5 cys)

Director
Vehicle Technology Programs
Code 211
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Director
Weapons Technology Programs
Code 212
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Dr. Robert G. Smith
Office of the Chief of Naval
Operations, OP987H
Personnel Logistics Plans
Washington, D.C. 20350

Office of Naval Research
Scientific Liaison Group
American Embassy, Room A-407
APO San Francisco 96503

Director
Naval Research Laboratory
Technical Information Division
Code 2627
Washington, D.C. 20375 (6 cys)

Director
Physiology Program
Code 441
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Special Assistant for Marine
Corps Matters
Code 100M
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Commanding Officer
ONR Branch Office
ATTN: Dr. J. Lester
Building 114, Section D
666 Summer Street
Boston, MA 02210

Commanding Officer
ONR Branch Office
ATTN: Dr. C. Davis
536 South Clark Street
Chicago, IL 60605

Commanding Officer
ONR Branch Office
ATTN: Dr. E. Gloye
1030 East Green Street
Pasadena, CA 91106

Department of the Navy

Chief
Aerospace Psychology Division
Naval Aerospace Medical Institute
Pensacola, FL 32512

Commanding Officer
Naval Health Research Center
San Diego, CA 92152

Dr. Fred Muckler
Navy Personnel Research and
Development Center
Manned Systems Design, Code 311
San Diego, CA 92152

Navy Personnel Research and
Development Center
Code 305
San Diego, CA 92152

Navy Personnel Research and
Development Center
Management Support Department
Code 210
San Diego, CA 92152

CDR P. M. Curran
Human Factors Engineering Division
Naval Air Development Center
Warminster, PA 18974

Dr. Lloyd Hitchcock
Human Factors Engineering Division
Naval Air Development Center
Warminster, PA 18974

Dr. A. L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, D.C. 20380

Mr. Ronald A. Erickson
Human Factors Branch
Code 3175
Naval Weapons Center
China Lake, CA 93555

LCDR William Moroney
Human Factors Engineering Branch
Code 1226
Pacific Missile Test Center
Point Mugu, CA 93042

Human Factors Section
Systems Engineering Test
Directorate
U.S. Naval Air Test Center
Patuxent River, MD 20670

Human Factors Engineering Branch
Naval Ship Research and Development
Center, Annapolis Division
Annapolis, MD 21402

Mr. Warren Lewis
Human Engineering Branch
Code 8231
Naval Ocean Systems Center
San Diego, CA 92152

Dr. Robert French
Naval Ocean Systems Center
San Diego, CA 92152

Dr. Ross L. Pepper
Naval Ocean Systems Center
Hawaii Laboratory
P.O. Box 997
Kailua, Hawaii 96734

Other Government Agencies

Dr. Robert R. Mackie
Human Factors Research, Inc.
5775 Dawson Ave.
Goleta, CA 93017

Dr. T. B. Sheridan
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

Dr. Arthur I. Siegel
Applied Psychological Services, Inc.
404 East Lancaster Street
Wayne, PA 19087

Defense Documentation Center
Cameron Station, Bldg. 5
Alexandria, VA 22314 (12 cys)

Dr. Stephen J. Andriole
Director, Cybernetics Technology Office
Defense Advanced Research Projects Agency
1400 Wilson Blvd
Arlington, VA 22209

Journal Supplement Abstract Service
American Psychological Association
1200 17th Street, N.W.
Washington, D.C. 20036 (3 cys)

Dr. Willam A. McClelland
Human Resources Research Office
300 N. Washington Street
Alexandria, VA 22314

Dr. James H. Howard
Department of Psychology
Catholic University
Washington, D.C. 20064

Dr. Jesse Orlansky
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Dr. Robert G. Pachella
University of Michigan
Department of Psychology
Human Performance Center
330 Packard Road
Ann Arbor, MI 48104

Dr. Stanley Deutsch
Office of Life Sciences
National Aeronautics and Space Administration
600 Independence Avenue
Washington, D.C. 20546

Dr. J. Miller
National Oceanic and Atmospheric Administration
11400 Rockville Pike
Rockville, MD 20852

Dr. William Howell
Department of Psychology
Rice University
Houston, TX 77001

Dr. Alphonse Chapanis
Department of Psychology
The Johns Hopkins University
Charles and 34th Streets
Baltimore, MD 21218

Dr. Robert Fox
Department of Psychology
Vanderbilt University
Nashville, TN 37240

Other Organizations

Dr. Harry Snyder
Department of Industrial Engineering
Virginia Polytechnic Institute and
State University
Blacksburg, VA 24061

Dr. J. A. Swets
Bolt, Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. William R. Uttal
Department of Psychology
Gartley Hall
University of Hawaii at Manoa
Honolulu, Hawaii 96822

Dr. W. S. Vaughan
Oceanautics, Inc.
422 6th Street
Annapolis, MD 21403

Dr. Robert Williges
Human Factors Laboratory
Virginia Polytechnical Institute
and State University
130 Whittemore Hall
Blacksburg, VA 24061

Dr. Gershon Weltman
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Department of the Air Force

U.S. Air Force Office of Scientific
Research
Life Sciences Directorate, NL
Bolling Air Force Base
Washington, D.C. 20332

Dr. Donald A. Topmiller
Chief, Systems Engineering Branch
Human Engineering Division
USAF AMRL/HES
Wright-Patterson AFB, OH 45433

Air University Library
Maxwell Air Force Base, AL 36112

Dr. Gordon Eckstrand
AFHRL/ASM
Wright-Patterson AFB, OH 45433